Audiovisual Perception of Dysarthric

Speech in Older Adults Compared to Younger Adults

by

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ABSTRACT

Everyday speech communication typically takes place face-to-face. Accordingly, the task of perceiving speech is a multisensory phenomenon involving both auditory and visual information. The current investigation examines how visual information influences recognition of dysarthric speech. It also explores where the influence of visual information is dependent upon age. Forty adults participated in the study that measured intelligibility (percent words correct) of dysarthric speech in auditory versus audiovisual conditions. Participants were then separated into two groups: older adults (age range 47 to 68) and young adults (age range 19 to 36) to examine the influence of age. Findings revealed that all participants, regardless of age, improved their ability to recognize dysarthric speech when visual speech was added to the auditory signal. The magnitude of this benefit, however, was greater for older adults when compared with younger adults. These results inform our understanding of how visual speech information influences understanding of dysarthric speech.

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I. INTRODUCTION

Spoken communication occurs in a variety of settings, but face-to-face interactions provide a rich set of visual information that coincides with the acoustic signal of speech. There is abundant evidence that access to the visual information (i.e., the speaking face) facilitates speech understanding, particularly in a noisy environment or when the speech signal is otherwise degraded (Gosselin & Gagne, 2011; Gordon & Allen, 2007; Pilling & Thomas, 2011; Sommers, Tye-Murray, & Spehar, 2005; Winneke & Phillips, 2011). It is thought that the visual cues provide converging evidence for phoneme identity, primarily through place of articulation cues (MacDonald & McGurk, 1978). This serves to disambiguate the degraded acoustic cues. There is a large body of evidence supporting the visual benefit in speech perception. This has been shown across a range of different types of speech, including normal speech, artificially degraded speech, and naturally degraded speech (Davis & Kim, 2004; Gosselin & Gagne, 2011; Gordon & Allen, 2007; Helfer, 1997; Hubbard & Kushner, 1980; Kaiser, Kirk, Lahs, & Pisoni, 2003; Pilling & Thomas, 2011; Sommers, Tye-Murray, & Spehar, 2005; Winneke & Phillips, 2011).

Normal speech stimuli are created using typical speech produced by a speaker without any deficits in speech production or history of speech disorders. Audio-visual (AV) conditions of normal speech are perceived more successfully than auditory-only (AO) conditions by listeners (Davis & Kim, 2004; Helfer, 1997; Hubbard & Kushner, 1980; Kaiser, Kirk, Lahs, & Pisoni, 2003). Helfer (1997) suggested visual information is supplementary to the normal auditory signal. Davis and Kim (2004) suggested that motor speech schemas are activated in listeners when perceiving AV stimuli, which subsequently improves perceptual performance when recognizing speech in AV conditions. However, Cienkowski and Carney's (2002) results contrast, stating there is no significant change in performance from AO to AV conditions. All of the listener's scores were above 98% percent words correct in both conditions demonstrating a ceiling effect in performance—indeed the fact that only a 2% increase is possible may explain the insignificant findings. In another study, Kaiser et al. (2003) examined speech perception in individuals with normal hearing and individuals with cochlear implants. Both groups performed better in AV conditions compared to AO conditions.

Artificially degraded speech is typical speech produced by a speaker without any speech disorders that is then digitally degraded by adding noise or compressing the signal. The literature shows that the benefit of processing speech in AV conditions relative to AO conditions is also present with artificially degraded speech (Gosselin & Gagne, 2011; Gordon & Allen, 2007; Pilling & Thomas, 2011; Sommers, Tye-Murray, & Spehar, 2005; Winneke & Phillips, 2011). Pilling and Thomas (2011) studied the perception of spectrally distorted speech. Spectrally distorted speech is perceived similarly to normal speech perceived through a cochlear implant. Pilling and Thomas distorted the speech signal through a noise-vocoder to stimulate the signal of a cochlear implant. The healthy young participants' performance in the AV conditions exceeded that of the AO condition (Pilling & Thomas, 2011).

Naturally degraded speech is speech degraded due to an impairment of speech production that could be caused by atypical structure, such as cleft palate or laryngectomy, or a motor speech disorder, such as dysarthria or apraxia of speech. Hubbard and Kushner (1980) researched the perception of esophageal speech, in addition to the perception of normal speech in normal hearing adult listeners. Esophageal speech is produced by post-laryngectomy individuals using vibrations of the esophagus because the vocal folds and larynx were surgically removed. Listener performance was more accurate in the AV condition compared to the AO condition, supporting the notion that vision supports perception of naturally degraded speech as well.

Perceptual research with dysarthria between AO and AV conditions, however, is not so conclusive (Garcia & Cannito, 1996; Garcia & Dagenais, 1998; Hustad & Cahill, 2003; Hustad, Dardis, & McCourt, 2007; Keintz, 2011; Keintz, Bunton, & Hoit, 2007). Keintz (2011) found significant benefit from visual information of one speaker with mild dysarthria. However, Keintz, Bunton, and Hoit (2007) found significant visual benefit only in speakers with moderate to severe dysarthria, in contrast to other studies on dysarthria (Hustad & Cahill, 2003; Hustad, Dardis, & McCourt, 2007). Garcia and Cannito (1996) studied gestures and other factors in addition to AV conditions and found AV performance was greater than AO performance when collapsed across all experimental factors. There are many variables that could result in these inconsistent findings including dysarthric severity, dysarthria type, type of stimuli (e.g., syllables, phrases, sentences, predictive or non-predictive, etc.), calculation of intelligibility, or listener profiles.

The variable findings of the effects of vision on the perception of dysarthric speech may also relate to the fact that the speaking face may not provide complementary information to the acoustic signal. For example, muscle paralysis or movement incoordination may result in visual cues that are inconsistent with, for example, the place of articulation of the target phonemes. Incongruent information may result in a visual decrement in such cases. To date, we know of no studies that have examined this possibility in a systematic way.

A final issue that has surfaced in studies of visual benefit to speech perception deals with the age of the perceiver. This is not surprising given the studies that have shown acoustic-only information is more effectively perceived by younger than older listeners. Often research has shown that younger adults perform better than older with, for example, time-compressed speech or speech in noise (Gordon-Salant & Fitzgibbons, 2003; Versfeld & Dreschler, 2001). Yet, other studies targeting older adults in AO versus AV conditions found that there is no significant difference in recognizing speech under these two conditions (Brault, Gilbert, Lansing, McCarley, & Kramer, 2010; Cienkowski & Carney, 2002). For example, Cienkowski and Carney (2002) found that all older adults scored above 98% for intelligibility in both AO and AV conditions, however, the ceiling effect may be responsible for their lack of findings. Brault, Gilbert, Lansing, McCarley, and Kramer (2010) found similar results; however, their study included a sub-group of participants with hearing loss. The findings demonstrated that the sub-group with hearing loss did demonstrate improvements in AV conditions. Brault and colleagues (2010) hypothesized that AV presentation modalities are beneficial only when speech and/or hearing is degraded. They replicated their initial experiment with artificially degraded speech in noise (Brault, Gilbert, Lansing, McCarley, & Kramer, 2010) and validated this speculation finding significant improvement in AV conditions using the degraded speech stimuli with participants with normal hearing.

Research comparing AO and AV conditions of artificially degraded speech between younger and older age groups have varying results (Gordon & Allen, 2009; Gosselin & Gagne, 2011; Sommers, Tye-Murray, & Spehar, 2005; Winneke & Phillips, 2001). Gordon and Allen (2009) found equivalent benefit between older and younger groups when provided with visual information. Additionally, this study modified the visual signal into a clear condition or a blurred condition to identify the participants' dependence on clear visual information. When the visual signal was blurred, the older adults' visual enhancement decreased significantly, while the younger adults' visual enhancement did not change. The older adults required a clear visual signal to benefit and the younger adults' performance was consistent across blurred and clear visual signals. This suggests younger adults may not rely as heavily on the visual information as older adults.

Also using speech in noise, Winneke and Phillips (2011) researched intelligibility of speech in noise between age groups. They found that older adults benefited from AV stimuli as compared to AO stimuli and visual-only stimuli. Their study used non-degraded visual speech stimuli with acoustic degradation. These stimuli provide typical articulatory visual cues to the participants as compared to the atypical articulatory patterns associated with dysarthria. This is worthy of noting due to the fact that participants benefited from visual cues of typical articulatory information. Overall, it seems that older adults' performance on degraded speech tasks improve when provided with visual information due to reliance on the visual signal if the AO stimuli does not result in a ceiling effect.

The visual enhancement (VE) score has been used in the existing literature to measure the benefit of visual information in AV conditions compared to AO conditions (Gordon & Allen, 2009; Sommers, Tye-Murray, & Spehar, 2005; Tye-Murray, Sommers, & Spehar, 2007; Winneke & Phillips, 2011). This calculation scales visual enhancement to each participant's initial audio-only score in the denominator to eliminate the bias of simply subtracting audio-only (AO) scores from audiovisual (AV) scores. The computed VE score represents the benefit of the added visual information scaled to the baseline AO score. AO is subtracted from AV in the numerator to demonstrate visual benefit and then is divided by AO subtracted from one to scale the benefit. VE is calculated through using the following formula:

$$VE = (AV-AO) / (1-AO)$$

A few studies have explored VE as a means to compare performance in younger and older adults (Gordon & Allen, 2009; Sommers, Tye-Murray, & Spehar, 2005; Winneke & Phillips, 2011). Sommers and colleagues (2005) found that, while younger adults performed better (greater intelligibility scores) than older adults, both groups benefited equally from visual information—that is, no significant difference in VE scores. Gordon and Allen (2009) found that both younger and older adults demonstrated VE in AV conditions. The older adult group demonstrated minimal VE when the visual signal was blurred suggesting older adults relied on the visual signal more than the younger adults. Similarly, Winneke and Phillips (2011) found greater VE in older adults compared to younger adults. The existing literature is inconsistent between age groups, but in general individuals seem to gain VE from the visual signal in addition to the audio signal.

Dysarthria is prevalent in wide range of ages, from children to adults. Our study is relevant to the older adult population with dysarthria. Accordingly, spouses and friends of these older individuals with dysarthria will primarily include the older adult population. Given the inconclusive findings in existing literature with AO and AV processing of dysarthric speech and the fact that all studies examined processing with younger adults, the purpose of the current study was to investigate the influence of visual speech information on perceptual processing of dysarthric speech, with both younger and older adults. The following key questions were addressed: (1) Does the addition of visual speech information enhance recognition of dysarthric speech? (2) Is this effect of adding visual speech information robust in both younger and older adult populations? (3) Do younger and older adult populations display different levels of benefit from adding visual speech information? The results will advance our understanding of the perception of dysarthric speech.

II. METHOD

A. Participants

Data were collected from 20 younger adults (YA) (16 females and 4 males) ages ranging from 19 years to 36 years (M=24.8, SD= 4.76) and 20 older adults (OA) (15 females and 5 males) ages ranging from 47 years to 68 years of age (M= 56.1, SD= 5.08). All participants met the following criteria: (a) native speakers of American English, (b) self-reported normal or corrected vision (e.g., glasses, contact lenses), (c) self-reported normal or corrected hearing (e.g., working hearing aids), (d) no identified learning or cognitive disabilities, (e) no significant experience with individuals with motor speech disorders. All participants completed a minimum of a high-school education. YA participants were recruited from the Arizona State University (ASU) undergraduate and graduate student classes in addition to peers of ASU students. OA participants were recruited from the family members, friends, and local members of the community. Participants received either course credit or $10 cash for participating in the study.

B. Speech Stimuli

One male native speaker (26 years) of American English, with moderate mixed ataxic dysarthria secondary to traumatic brain injury provided the speech stimuli for the present study. His speech was characterized by a perceptually slow speaking rate with a tendency toward equal and even syllable duration (scanning speech), excessive loudness variation, and irregular articulatory breakdown—which are considered cardinal features of ataxic dysarthria, according to the Mayo Classification System (Darley, Aronson, & Brown, 1969a, 1969b; Duffy, 2005). Speech intelligibility on a random selection of 15 predictive sentence stimuli was rated to be 55%, according to perceptual judgements from two blinded listeners transcribing the sentences.

Audiovisual speech stimuli were collected in a sound-attenuated booth with a Shure KSM 32 microphone and Canon XA10 video camera, positioned to capture a view of the speaker’s head and shoulders, against a plain black backdrop. Speech output elicited during the speech tasks was recorded digitally to a memory card at 48 kHz (16 bit sampling rate) and stored as individual .mts files. Speech stimuli consisted of forty semantically anomalous phrases (see Appendix A). Speech stimuli were presented to the speaker via a PowerPoint presentation displayed on a laptop positioned directly in front of the speakers. The speaker was encouraged to use his ‘normal speaking’ voice while reading the stimuli aloud and looking directly into the video camera. All .mts files were then opened into Adobe Premiere Pro. Audio portions of the stimuli files were imported into Adobe Audition for editing, where each file underwent noise reduction, converted to mono, and normalized to -3dB. Audi portions were then imported back into Adobe Premiere Pro, and realigned with the corresponding video. Edited speech stimuli files were then converted into .avi and .wav files using Prism Video File Converter.

C. Procedure

The experiment was conducted in a quiet room, either in the Motor Speech Laboratory at ASU or at the investigator or participants’ home. All environments were controlled to minimize visual distraction and background noise. Participants all signed a consent form and completed a basic case history form prior to participating in the experiment. Participants were seated in front of a computer monitor and fitted with headphones (Sennheiser HD 280 PRO). Prior to beginning the experimental task, participants were given a brief overview of the task instructions by the investigator. Detailed written instructions were provided in the experimental procedure, pre-programmed in Presentation Software Version 16.4 Build 06.07.13. Participants were instructed to transcribe 40 semantically anomalous phrases presented in an audio condition and then an audio-visual condition. Participants were told to pay close attention to the stimuli, regardless of which condition it was presented in. OA participants completed a volume check to establish a comfortable volume level to present the stimuli through the headphones. The volume check consisted of the investigator played one .wav audio file of an experimental phrase using Video Lan Client Media Player 2.0.7 and adjusted the volume according to listener report. Output data from each participant was labeled with a code (i.e., OA_P01 for older adult participant 1).

D. Data Analysis

The total data set consisted of 40 transcript files for analysis. All transcript files were analysed for a measures of percent words correct (PWC). Words correct were defined as those that matched the intended target exactly, as well as those that differed only by the tense "ed" or the plural "s." In addition, substitutions between ''a'' and ''the'' were regarded as correct.

Each participant's PWC scores for audio-only (AO) and audiovisual (AV) conditions were used to determine Visual Enhancement (VE). VE is a calculation frequently used in audiovisual research (Gordon & Allen, 2009; Sommers, Tye-Murray, & Spehar, 2005; Winneke & Phillips, 2011). As previously discussed, VE is calculated using the formula:

$$VE = (AV-AO) / (1-AO)$$

E. Reliability of File Analysis

Twenty-five percent of all YA and OA data files were randomly selected and coded a second time by the original coder (intra-judge) and by a second trained judge (inter-judge) to obtain reliability estimates for the coding. Discrepancies between the reanalysed data and the original data revealed that agreement was high (all correlations $r > .95$), with only minor absolute differences.

III. RESULTS

Figure 1 reflects the mean PWC scores for all 40 listeners' transcribed phrases in A and AV conditions. A paired-samples *t*-test revealed a significant difference between condition, $t(39) = -11.391$, $p < .001$ Thus, listeners were better at recognizing dysarthric speech under AV conditions—when auditory information was supplemented with visual information—relative to A conditions.

Figure 1: Audio-only and Audiovisual Intelligibility

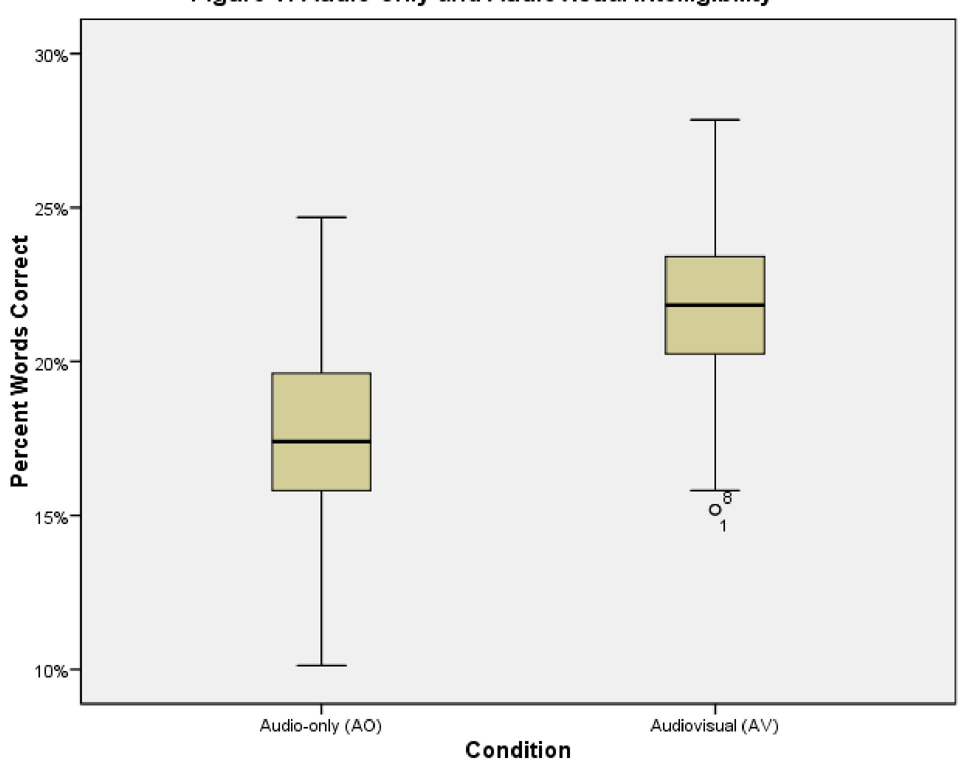


Figure 2 reflects the mean PWC scores for transcribing phrases presented in A and AV conditions, when separated according to age categories. A one-way ANOVA, with condition (A or AV) and age (YA or OA) as between subject variables. The ANOVA revealed no significant interaction between factors, $F(1,76) = 7.211$, $p = .699$. The reverse ANOVA revealed a non-significant p-value of 0.516 when separating the groups by age. However, paired t-tests within each age group revealed a significant main effect of condition. Thus, both age category groups were better at recognizing dysarthric speech under AV conditions relative to AO conditions, $p < .001$.

Figure 2: Audio-only and Audiovisual Intelligibility Separated by Age

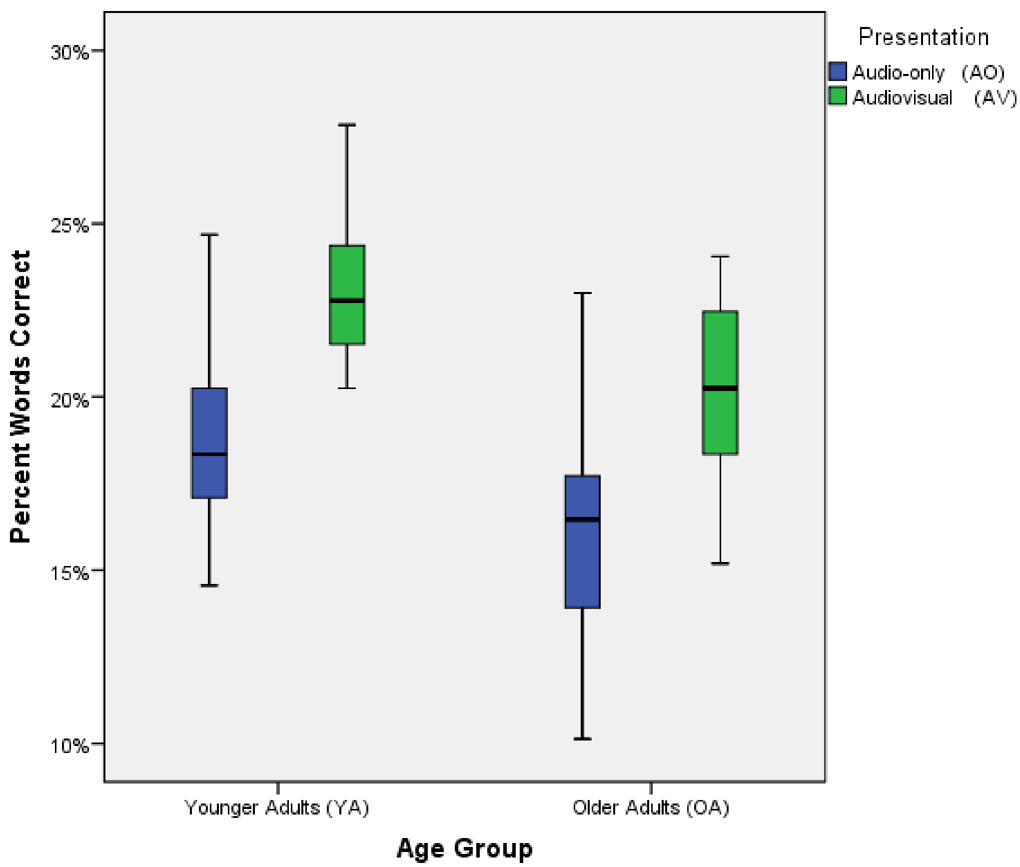
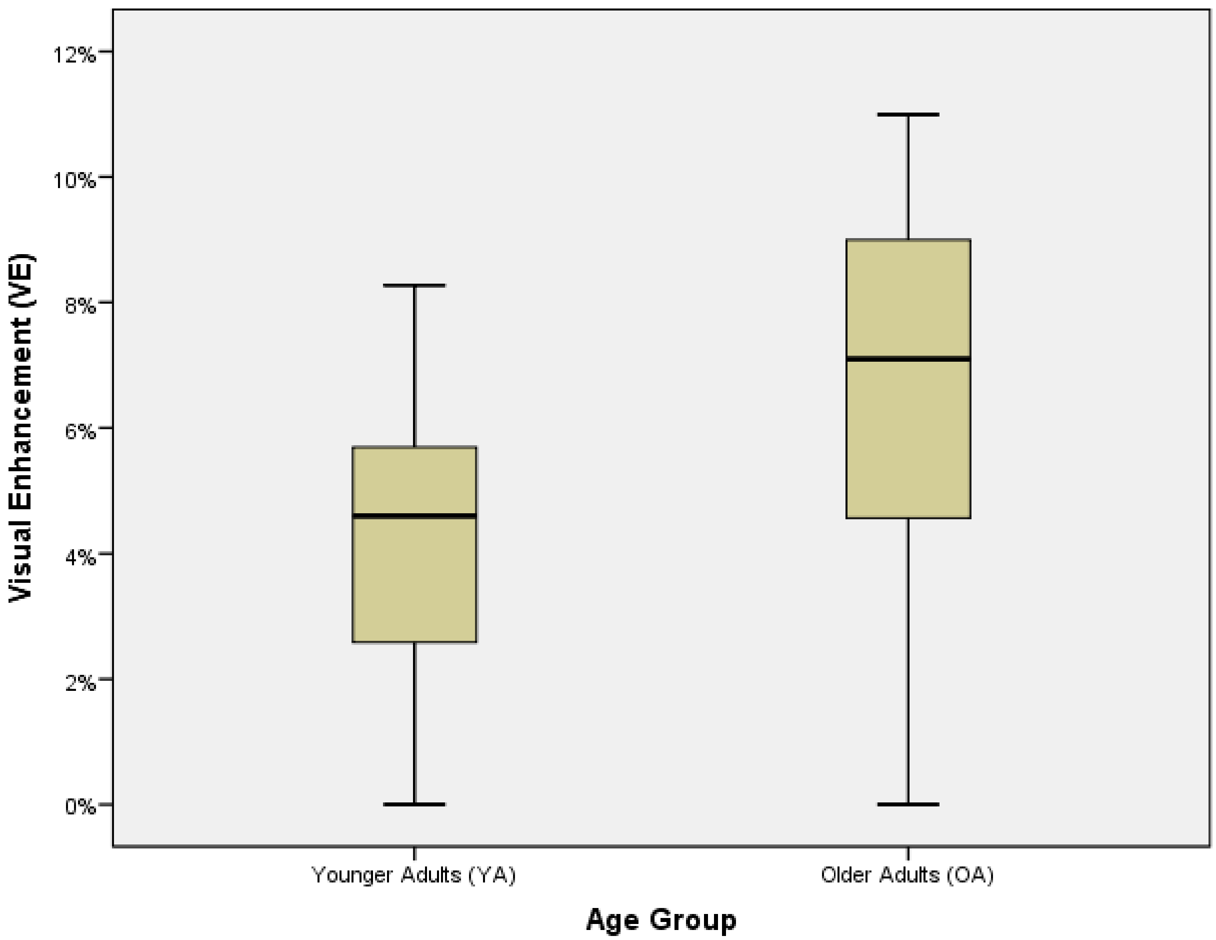


Figure 3 reflects the mean Visual Enhancement (VE) scores for age groups, YA and OA. An independent-measures *t*-test revealed a significant difference between VE scores for age groups, $t(38) = 3.278$, $p = .002$. Thus, OA benefited more from adding visual speech information to the auditory information. Additionally, a Cohen's *d* of 1.03 was calculated between groups indicating a large effect size.

Figure 3: Visual Enhancement Separated by Age



IV. DISCUSSION AND CONCLUSIONS

The present study investigated the effect of visual information on the intelligibility of dysarthric speech. The results suggest that an audiovisual benefit to speech intelligibility is differential for younger and older adults. Examining all participants, intelligibility was significantly greater in the AV condition versus AO condition. Importantly, this audiovisual benefit was robust when participants were examined in age-divided cohorts. These results are discussed in more detail below.

The findings in the present study are consistent with past research that visual information complements the auditory signal, resulting in improved intelligibility of normal speech (Davis & Kim, 2004; Helfer, 1997) and artificially degraded speech (Gosselin & Gagne, 2011; Gordon & Allen, 2007; Pilling & Thomas, 2011; Sommers, Tye-Murray, & Spehar, 2005; Winneke & Phillips, 2011). Interestingly, dysarthric speech, as used in the present investigation, is a form of *natural* degradation. The small number of studies that have examined AV processing with dysarthric speech have reported inconsistent results (Garcia & Cannito, 1996; Garcia & Dagenais, 1998; Hustad & Cahill, 2003; Hustad, Dardis, & McCourt, 2007; Keintz, 2011; Keintz, Bunton, & Hoit, 2007). Our study adds support to this existing body of literature that, when listening to dysarthria, additional visual information is provided in AV conditions to assist the listener in perceiving the message, including articulatory movements associated with speech sounds. Despite the neuromuscular deficits in individuals with dysarthria, and minimal articulatory excursions, mapping the degraded acoustic signal to the degraded visual signal correlates results in improved understanding.

The novelty of the current study is the notion that AV benefit is dependent upon age. The existing body of research on the contributions of visual information to understanding dysarthric speech were conducted with younger adults. It is critical to assess the generalization of these findings to the most prevalent communication partners of older individuals with dysarthria, who are also most likely within the older population. The current body of research assessing the possible age-related differences of VE use experimentally, not naturally degraded speech. For instance, Sommers, Tye-Murray, and Spehar (2005) found no significant difference between age groups in a listening task where the speech stimuli were originally produced by a normal speaker then artificially degraded. Although the audio stimuli were degraded, the visual stimuli from the normal speaker were not altered, therefore providing inconsistent cues and distorting the complementary nature of the auditory and visual information. Our study utilized the naturally degraded audio and visual signals produced by the speaker with dysarthria.

In the current study of naturally degraded speech, we found that visual enhancement (VE) was, in fact, significantly greater in older participants than in younger participants. In other words, older adults benefit more from adding visual speech information. A possible explanation lays in the idea that, due to typical declines in hearing acuity (Pichora-Fuller & Souza, 2003), older adults learn to rely more on visual cues over time. Not surprisingly, of course, there is a wide range of intelligibility scores, across all participants, regardless of age group. Some participants benefitted greatly, where some participants did not benefit at all. The identification of common characteristics of individuals who scored low compared to those who scored high should be researched further. Left or right handedness indicating left or right brain dominance or musical background would be characteristics for possible further research.

Of course, there are limitations in the present investigation, where the intelligibility of one speaker with moderate mixed ataxic dysarthria secondary to a traumatic brain injury is examined. There are numerous types and severities of dysarthria that exist with varying speech characteristics; given that each has a different profile of neurologic damage and effect of neuromuscular production, it is possible the VE is different across dysarthria presentations. For example, replicating this study using stimuli including dysarthric speech secondary to facial paralysis may not yield the same results. Future research should expand to varying severities and types of dysarthria to fully understand the benefit of visual information offered to older adults. Further, the stimuli used were semantically anomalous, but syntactically correct, to ultimately allow for the examination of the lexical segmentation which is used to examine the cognitive strategies used to decode stress in speech. While outside of the current research question, the use of predictive phrases may offer predictions more comparable the benefit to be seen to conversational speech.

Importantly, these results bear on clinical practice of speech-language pathologists and the treatment for individuals with intelligibility disorders. First, many measures of intelligibility using unfamiliar listeners for clinical purposes utilize AO assessments. Using this standard as a proxy for the individual’s intelligibility disorder ignores the added value of visual information, afforded in daily conversations. If the standard measurements of intelligibility included AV conditions, performance differences would offer a more accurate reflection of daily communicative interactions. Next, this information supports the notion that clients with dysarthria should strongly consider utilizing AV methods of telecommunications (e.g., video chatting) over AO methods (e.g., telephone), when communicating with older adults. Understanding the differential magnitude of benefit available to older versus younger adults, by adding visual information, offers a springboard for many questions related to the cognitive processes associated with the perception of dysarthric speech.

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APPENDIX A

EXPERIMENTAL PHRASES

mode campaign for budget	1. amend estate approach
2. may the same pursued it	3. perceive sustained supplies
4. distant leaking basement	5. attack became concerned
6. resting older earring	7. unseen machines agree
8. sinking rather tundra	9. mistake delight for heat
10. narrow seated member	11. advance but sat appeal
12. listen final station	13. award his drain away
14. rocking modern poster	15. forget the joke below
16. functions aim his acid	17. submit his cash report
18. mark a single ladder	19. assume to catch control
20. vital seats with wonder	21. commit such used advice
22. balance clamp and bottle	23. indeed a tax ascent
24. measure fame with legal	25. beside a sunken bat
26. model sad and local	27. appear to wait or turn
28. bolder ground from justice	29. embark or take her sheet
30. cool the jar in private	31. account for who was knocked
32. rode the lamp for teasing	33. had eaten junk and train
34. frame her seed to answer	35. to sort but fear inside
36. mate denotes a judgement	37. secure but lease apart
38. signal breakfast pilot	39. its harmful note abounds